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INDEX

Pag.

B. Stener, Experimental evaluation of the hypothesis of ligamento-muscular protective reflexes. I. A method for adequate stimulation of tension receptors in the medial collateral ligament of the knee joint of the cat, and studies of the innervation of the ligament 5

S. Andersson and B. Stener, Experimental evaluation of the hypothesis of ligamento-muscular protective reflexes. II. A study in cat using the medial collateral ligament of the knee joint 27

I. Petersén and B. Stener, Experimental evaluation of the hypothesis of ligamento-muscular protective reflexes. III. A study in man using the medial collateral ligament of the knee joint 51

FROM THE DEPARTMENT OF PHYSIOLOGY, UNIVERSITY OF GÖTEBORG, GÖTEBORG, SWEDEN.

EXPERIMENTAL EVALUATION OF THE HYPOTHESIS OF LIGAMENTO-MUSCULAR PROTECTIVE REFLEXES

I. A method for adequate stimulation of tension receptors in the medial collateral ligament of the knee joint of the cat, and studies of the innervation of the ligament

By

BERTIL STENER

ABSTRACT

STENER, B. Experimental evaluation of the hypothesis of ligamento-muscular protective reflexes. I. A method for adequate stimulation of tension receptors in the medial collateral ligament of the knee joint of the cat, and studies of the innervation of the ligament. *Acta physiol. scand.* 1959. *48.* Suppl. 166. 5—26. — A method is described for effecting a large increase in the ligament's tension. The ligament is loaded *in situ* transversely to the line of the leg. The slight dissection required by the method involves no appreciable damage to afferent nerve fibres of the ligament. A study was made of the effect of loading the ligament on the impulse flow in the medial and posterior articular nerves. The course of the branches of these two nerves in relation to different parts of the ligament was investigated by probing with auditive registration of the impulse response and by anatomical dissection.

For a long time it has been assumed that articular ligaments, instead of acting only as purely mechanical obstacles to abnormal movements of a joint, have as a most important task the initiation, via tension receptors, of a reflex contraction of the muscles capable of opposing the abnormal movement. The principle behind this assumption has been put forward by several authors (PARTRIDGE 1924, POLICARD 1936, PALMER 1938, 1944, 1957, 1958) and it appears in text-books dealing with traumatological subjects. A survey of the literature showed, however, that the teleologically attractive hypothesis of ligamento-muscular protective reflexes had not been confirmed by experiments and the present study in the cat was therefore undertaken.

The medial collateral ligament of the knee joint was chosen for the experiments because useful basic data have already been collected for this joint and ligament in the cat.

GARDNER (1944) found that the knee joint of the cat is innervated both by the muscle nerves of quadriceps and sartorius and also by two special articular nerves, which he called the *medial nerve* and the *posterior nerve*. The medial nerve, which is sometimes doubled, arises from the femoral nerve and follows the descending genicular artery.[1] The posterior nerve issues from the tibial nerve in the popliteal fossa. In those cases where there are two medial nerves the lower, according to SKOGLUND (1956), usually arises from the obturator nerve.

ANDREW and DODT (1953) and SKOGLUND (1956), using different techniques, studied the innervation fields of the medial and posterior articular nerves. According to their diagrams all but the most distal part of the medial collateral ligament lies within the innervation field of the medial nerve, whereas no part of it lies within the innervation field of the posterior nerve. GARDNER (1944), on the other hand, found that branches from the posterior nerve reach the ventromedial as well as the ventrolateral aspect of the joint. It thus seemed

[1] Referred to by GARDNER as 'the genu suprema branch of the femoral artery'.

possible, but not certain, that the posterior nerve might also contribute to the innervation of the ligament. Detailed information was needed about the relationship between the branches of the medial and posterior nerves and the medial collateral ligament.

ANDREW and DODT (1953), ANDREW (1954) and SKOGLUND (1956) recorded large fibre action potentials from the medial nerve which ceased if the distal end of the medial collateral ligament was severed but reappeared if the cut end of the ligament was then loaded. These impulses were thought to originate in slowly adapting stretch receptors found in the ligament (ANDREW 1954, SKOGLUND 1956). In some experiments ANDREW (1954) even succeeded in recording impulses from the medial nerve when loading ligaments which, together with a short length of the nerve, had been dissected free from the joint and suspended in a bath of Locke's solution. According to ANDREW (1954) the deep surface of the ligament is devoid of myelinated fibre endings; these lie on its superficial surface.

GARDNER (1950), BESWICK *et al.* (1955), SKOGLUND (1956) and COHEN and COHEN (1956) demonstrated reflex motor actions by impulses in afferent fibres of the knee joint in the cat. In their investigations, however, no differentiation was made between ligamentary and extra-ligamentary receptors.

In a series of early experiments in the present study, the tension in the medial collateral ligament of the knee joint was increased by loading the ligament longitudinally after detaching it from the tibia. When this was done, however, no reflex muscular responses ascribable to ligamentary receptors were obtained. The results of these experiments disagreed with the hypothesis tested, but were not conclusive, as they could possibly be due to the ligament's innervation having been partly destroyed by the dissection involved. Thus the need arose for a method of bringing about a large increase in tension in the ligament without such preparatory dissection as might result in damage to afferent nerve fibres from the ligament. A method was worked out and is described in detail in what follows.

DESCRIPTION OF THE NEW PROCEDURE FOR INCREASING THE TENSION IN THE LIGAMENT

Dissection studies showed that there is a bursa (not mentioned in text-books of the anatomy of the cat) between the intermediate part of the medial collateral ligament and the tendon of that part of semimembranosus which inserts on the tibia (Fig. 1 b). When the knee joint is about half-way between full extension and full flexion (semiflexed) the ligament crosses the tendon almost at right angles. The tendon runs between the ligament and the tibia. The bursa extends along the entire intermediate third of the ligament and projects a few millimetres beyond its ventral and dorsal edges. Proximally the bursa communicates freely with the joint cavity beneath the medial meniscus (Fig. 2). The meniscus is fastened to the deep surface of the ligament. The superficial surface of the ligament's distal half is crossed by the thin, flat gracilis tendon. Superficially to this the *entire* ligament is covered by sartorius. In the cat this muscle is broad and flat and consists in principle of two parts: a *lateral* one, inserting on the tibia via the patellar ligament and the medial patellar ligament (Fig. 1 a), and a *medial* one, inserting directly on the tibia. Between these two parts the muscle is very thin.

With the knee joint semiflexed a small part of the ligament is exposed just distal to the joint line by incising the sartorius muscle (Fig. 1 a). This is done as far as possible along the length of the muscle fibres, using a dissecting microscope. Without stripping its covering layers of loose connective tissue the ligament's ventral and dorsal edges are identified. Incisions, approximately 1 mm in length, are made parallel and close to either edge of the ligament, thus opening the bursa described above (Fig. 1 b). Thereafter, a perlon thread (0.5 mm in diameter) is inserted through the dorsal opening and pulled out through the ventral. With this thread the ligament can be subjected *in situ* to a large increase in tension. Fig. 2 shows the medial aspect of the knee joint in profile, with the medial collateral ligament and its adjacent structures drawn to scale. The proximal and distal halves of the ligament form the two arms of an obtuse angle and the loading thread is passed round

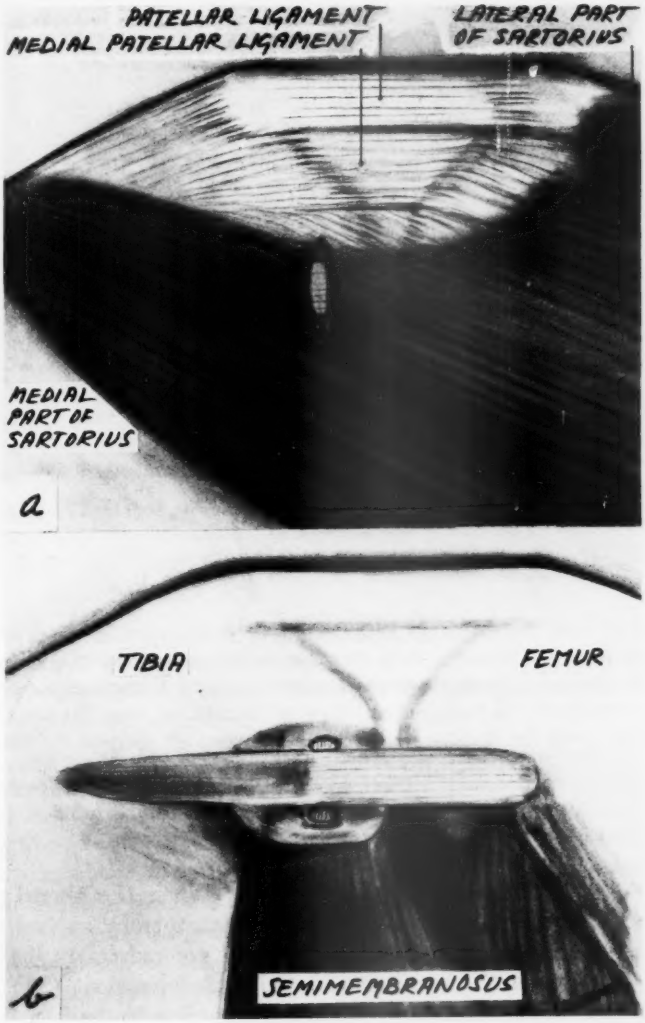

Fig. 1. The medial aspect of the right knee joint of the cat. a) The medial collateral ligament is exposed just distal to the joint line by a small incision in sartorius. b) The bursa between the ligament and the tibial tendon of semimembranosus; small holes have been made in the wall of the bursa dorsal and ventral to the ligament.

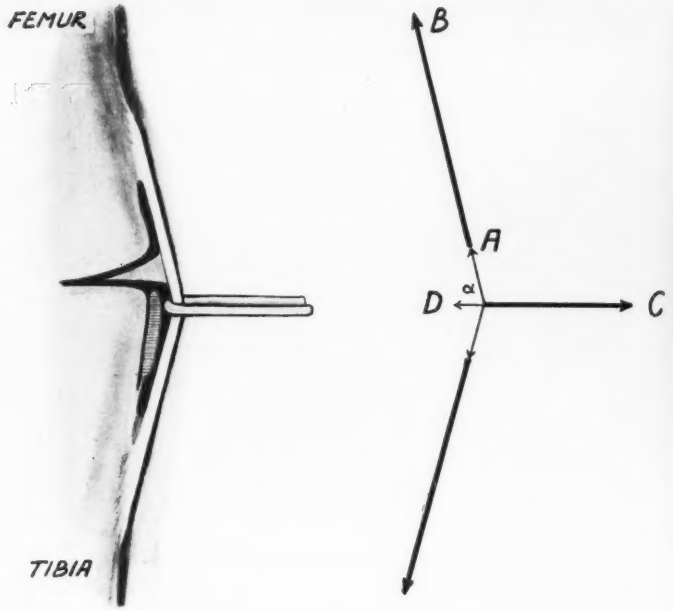

Fig. 2. Left: The medial collateral ligament of the knee joint of the cat seen in profile (drawn to scale). The medial meniscus is attached to the deep surface of the ligament. The tendon of semimembranosus below the meniscus is shown in cross section. A loading thread is passed through the bursa between the ligament and the tendon. Right: Diagram showing the increase in tension in the ligament during transverse loading. A = initial tension in the ligament resulting in the pressure D against the joint. B = increase in tension on loading the ligament with the force C.

the ligament where these arms meet. When the thread is loaded with a known force (C) the tension thereby applied to the ligament (A + B) can be calculated approximately if the angle between the two parts of the loaded ligament ($2\,\alpha$) is known. The calculation can be made according to the formula: $A + B = \frac{C}{2 \cos \alpha}$ assuming that the thread is loaded with a force sufficient to increase the tension in the ligament. Such increase in tension (B) first occurs when the loading force (C)

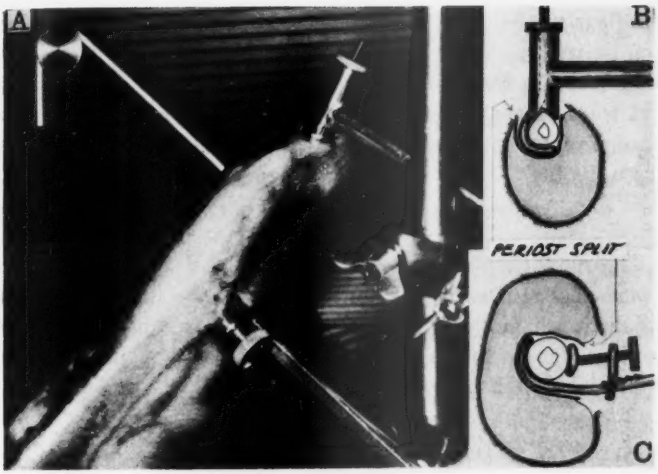

Fig. 3. The method of immobilizing the femur and the tibia for transverse loading of the ligament (see p. 11).

exceeds the pressure (D) exerted on the knee joint by the ligament's initial tension (A). The angle 2α cannot be measured accurately until the end of the experiment because to do this it is necessary to lay bare the entire ligament.

During the experiment it is important that the knee joint is immobilized. Fig. 3 shows the apparatus used. The femur (C) is approached from the lateral side by blunt dissection between vastus lateralis and anterior biceps. A longitudinal incision about 1 centimetre in length is made in the periost, which is then carefully freed all the way round with a raspatory. By this means the cortex of the bone is denervated at the site of application of the clamping arm (cf. HURRELL 1937). To clamp the tibia (B) it is easiest to approach from the ventromedial side. The force loading the ligament and the counterforces in the clamps act in parallel planes (A). In this way bending of the clamping arms is avoided even during heavy loading of the thread. The clamping arms are fixed in the apparatus in such a way that the knee joint, besides being

semiflexed, is held in a mid-way position between ab- and adduction as well as outward and inward rotation. In this position the tension in the medial collateral ligament is relatively weak, and the afferent impulse flow in the medial nerve reduced to a minimum (ANDREW and DODT 1953, ANDREW 1954, SKOGLUND 1956).

*

The next chapter contains an account of physiological and anatomical studies of the innervation of the medial collateral ligament which were made in order to show whether the new method for increasing the ligament's tension involves any appreciable damage to afferent nerve fibres of the ligament.

THE INNERVATION OF THE MEDIAL COLLATERAL LIGAMENT

These studies were principly concerned with two matters. Firstly, the effect on the impulse flow in the medial and posterior nerves while increasing the tension in the ligament by the new method, and secondly, the course of the branches of these nerves in relation to different parts of the ligament and to the site of the loading thread.

METHODS

Preparation. Thirty-five adult cats were used. Decerebration, pre- or intercollicularly, was performed by suction under ether after ligation of the carotid arteries. The animals were placed on a heated table and the rectal temperature was controlled. The femur and the tibia were immobilized and the loading thread was passed round the ligament according to the method described above. The medial nerve was exposed about 3 centimetres proximal to the knee joint by removing part of sartorius covering it. The nerve was then carefully freed, using a dissecting miscroscope, and cut so that a free stump, about 1 centimetre long, was obtained. In some animals the posterior nerve was also exposed and severed for impulse recording. This could

be done, without altering the position of the limb, by partial excision of the medial hamstrings together with dorsal retraction of the medial head of gastrocnemius.

Recording. The severed nerves were placed on silver wire electrodes for bipolar lead off in a paraffin bath. The temperature of the paraffin was maintained at 37° C by means of a heating lamp. The electrodes were connected, via an AC-amplifier, to a cathode-ray oscillograph and a loud-speaker. Action potentials led off from the nerves were photographed on continuously running bromid paper.

Stimulation. Receptors transmitting impulses through the medial and posterior nerves were stimulated in two ways — by loading the medial collateral ligament using weights attached to the loading thread, which was carried over a pulley, and by using a glass rod to probe within the innervation fields of the two nerves.

Anatomical dissection. When the recordings from the medial and posterior nerves had been completed, a study was made of the course of the branches of these nerves in relation to the ligament and the site of the loading thread, using a dissecting microscope.

RESULTS

A. The effect on the afferent impulse flow in the medial and posterior nerves while increasing the tension in the ligament

Recordings from the medial nerve were obtained in 35 cats (in 6 cases on both hind legs). In 11 of these cats there were two medial nerves and recordings were made from each. In 9 of the 35 cats recordings were also obtained from the posterior nerve.

During recording from the *medial* nerve the resting discharge, in terms of impulse frequency and number of active endings, was in most cases relatively small; according to the findings of previous authors this was to be expected, as the knee joint had been fixed in a semiflexed position. When the tension in the ligament was increased by hanging weights on the loading thread, an increased discharge was obtained in the nerve in

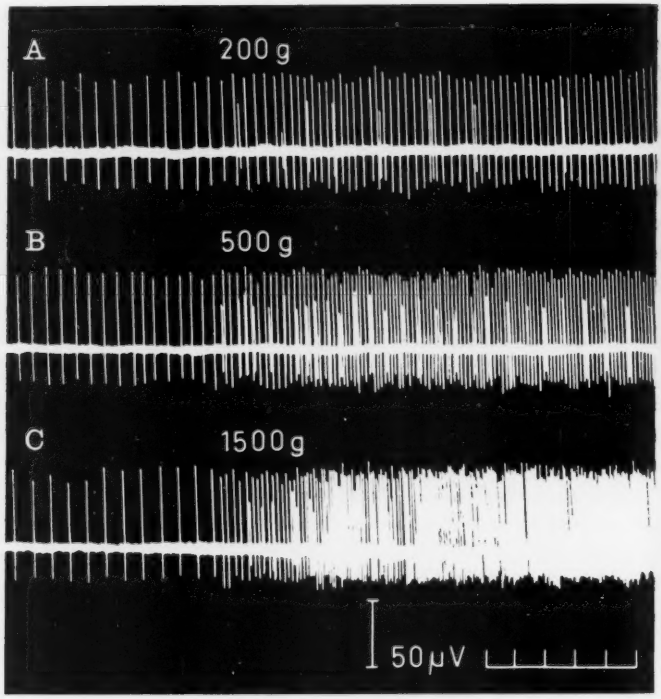

Fig. 4. Recordings from the medial nerve during transverse loading of the ligament. Time 0.1 sec.

all but 2 of the 35 animals. Fig. 4 illustrates one of the experiments, using 200, 500 and 1,500 g weights. The illustration is taken from a cat with only one medial nerve. The increase in discharge varied a good deal from case to case but was usually very considerable. In several cases it definitely exceeded that shown in Fig. 4. In the 11 cases where recordings were obtained from both an *upper* and a *lower* medial nerve the response when loading the ligament was virtually of the same magnitude in both nerves in 4 cases but larger in the lower in all the others.

During recording from the *posterior* nerve the resting discharge

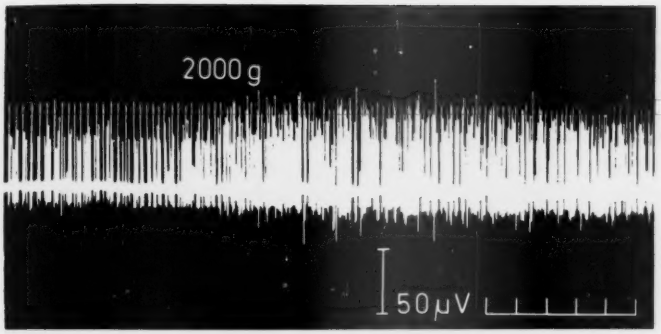

Fig. 5. Recording from the posterior nerve during transverse loading of the ligament. Time 0.1 sec.

was relatively large in most cases (cf. Fig. 5 to the left). The same observation was made by SKOGLUND (1956). In 8 of the 9 cases the discharge was clearly increased when the ligament was loaded, though in one not until more than 2 kilograms had been hung on the loading thread. Fig. 5 illustrates a recording from the posterior nerve. It was calculated that a weight of 2 kg hung on the thread increased the tension in the ligament to 3.6 kiloponds.[1]

In 11 of the experiments where recordings were made from the medial nerve, the minimum weight required to increase the impulse flow was determined. This 'threshold value' varied between 5 and 150 grams. The large discrepancy was probably due, at least in part, to differences in the initial tension in the ligament from case to case (cf. p. 10). During recording from the posterior nerve the resting discharge was too large to permit determination of such threshold values with any degree of certainty.

When the ligament is loaded in the manner described, certain mechanical effects are produced on extra-ligamentary structures because it is impossible to avoid a very slight medial deviation of the ligament, particularly at the point of application of the

[1] 1 kilopond = 1 kilogram force.

load. In 3 animals, where transverse loading of the ligament resulted in an especially large increase in discharge in the medial nerve, various dissections were made with the intention of showing that the increase in discharge was ascribable, at least in part, to ligamentary receptors:

Case 1. An incision was made along the entire ventral edge of the ligament, descending right down to the bone surface of the femur and the tibia; the medial meniscus was then cut free from the deep surface of the ligament. After this dissection the increase in discharge in the medial nerve during transverse loading of the ligament appeared to be very nearly as large as before.

Case 2. First, recordings were made to show that it was also possible to produce a large increase in discharge in the medial nerve by abduction at the joint. In order to eliminate as far as possible such effects of the abduction as could be ascribed to the stretching of structures other than the ligament, the whole ventral aspect of the joint was then cut open by a transverse incision, starting next to the ligament's ventral edge. Even after this dissection it was still possible to produce a large increase in discharge in the medial nerve by abduction at the joint.

Cases 1, 2 and 3. The ligament's distal end was detached from the tibia and loaded via a thread. In accordance with the findings of previous authors, this way of loading the ligament also induced a marked increase in discharge in the medial nerve.

B. Distribution of the branches of the medial and posterior nerves in relation to the ligament

In the majority[1] of cases where recordings were made from the medial and posterior nerves, the ventromedial aspect of the knee joint was probed in order to obtain an approximate conception of the innervation field of the nerve in question, with special reference to the ligament. A glass rod with a rounded

[1] Single medial nerve: 16 joints; two medial nerves: 11 joints; posterior nerve: 7 joints.

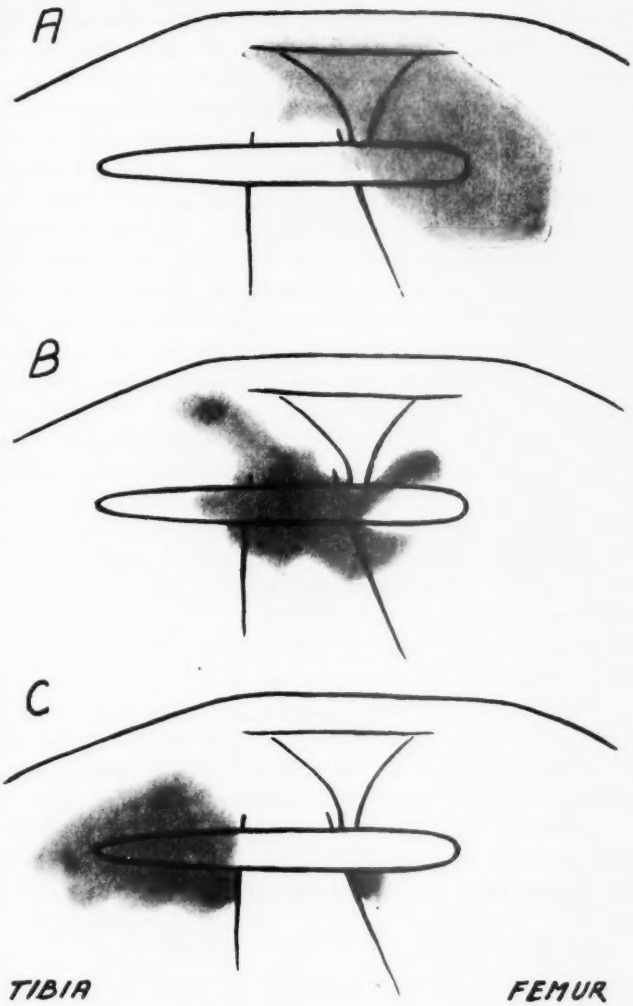

Fig. 6. The innervation fields, determined by probing, of A) the upper medial nerve, B) the lower medial nerve and C) the posterior nerve. The observations were made on one and the same knee joint.

head, 1.5 mm in diameter, was used for the stimulation and the impulse response was registered by ear. The pressure applied was very slight so that the effect on remote receptors should have been negligible. In what follows the term 'innervation field' stands for the area determinable by this method. Fig. 6 shows the result of probing in a case where recordings were made from *upper* and *lower medial* nerves (A and B) as well as from the *posterior* nerve (C). The innervation fields of these three nerves complemented each other. In respect of the medial collateral ligament the innervation fields of the upper and lower medial nerves overlapped, as did those of the lower medial nerve and the posterior nerve. In another case where clearly defined probing charts were obtained for these three nerves the overlap was even more pronounced. The ligament's proximal half thus lay within the innervation field of the upper medial nerve, while its proximal two thirds lay within the field of the lower medial nerve. The innervation field of the posterior nerve extended both in the form of a band, about 5 mm wide, right across the ligament at the level of the joint line and also over almost the entire distal half of the ligament.

The innervation fields of the medial and posterior nerves as determined by this method showed considerable variations from case to case. Nevertheless, the field of the medial nerve as a rule reached the patellar ligament and sometimes extended beyond this. Distally, the innervation field of the medial nerve only occasionally covered the ligament's distal end, regardless of whether there was one medial nerve or two. When there were two medial nerves their innervation fields nearly always overlapped to such an extent that the ligament's proximal half wholly or in part lay within the common field of these two nerves.

*

In 25 of the knee joints, after recordings had been made from the medial nerve, the course and branching of this nerve was

Fig. 7. Results from 10 of the anatomical dissections of the medial nerve. In G-J there were two medial nerves. The arrow-heads at the end of some branches indicate that these turned and went deep.

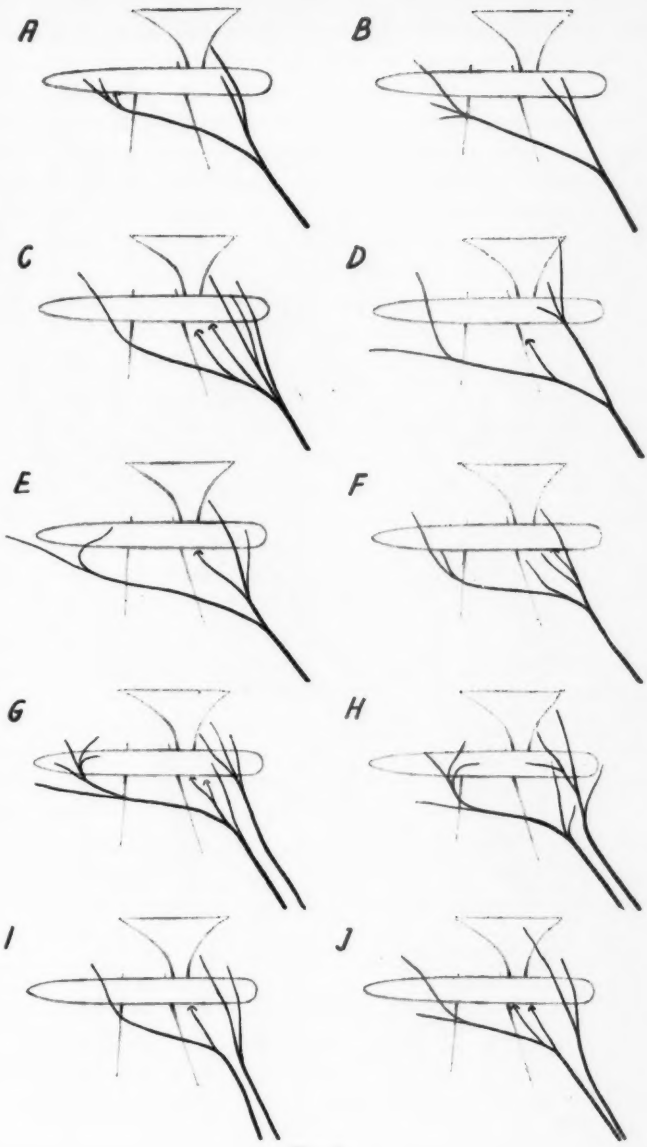

Fig. 7.

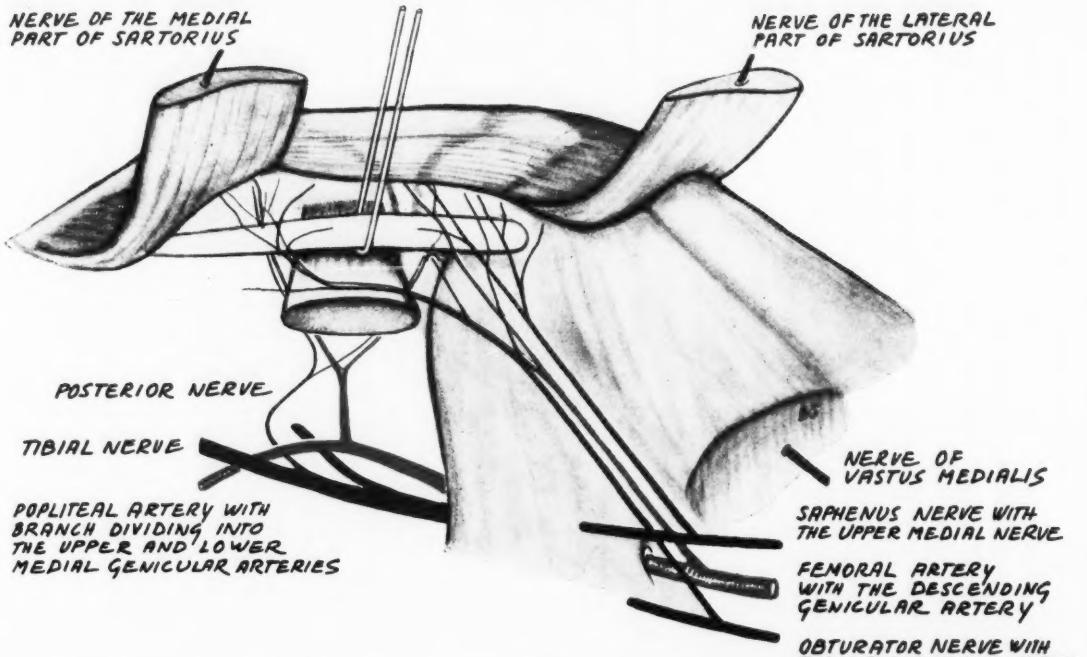
NERVE OF THE MEDIAL PART OF SARTORIUS
NERVE OF THE LATERAL PART OF SARTORIUS
POSTERIOR NERVE
TIBIAL NERVE
POPLITEAL ARTERY WITH BRANCH DIVIDING INTO THE UPPER AND LOWER MEDIAL GENICULAR ARTERIES
NERVE OF VASTUS MEDIALIS
SAPHENUS NERVE WITH THE UPPER MEDIAL NERVE
FEMORAL ARTERY WITH THE DESCENDING GENICULAR ARTERY
OBTURATOR NERVE WITH THE LOWER MEDIAL NERVE

Fig. 8.

studied by *dissection* under a microscope. In 8 of these cases there were two medial nerves. The posterior nerve was studied in the same way in 6 cases. The branches of the nerves were followed until they became so thin that they broke. Thereafter it was not possible to distinguish with certainty between nerve twigs and connective tissue or small vessels.

In almost every case it was possible to follow branches of the *medial nerve* right up to where they reached or crossed over the ligament's proximal third (Figs. 7 and 8). These branches ran more or less in the same direction as the main trunk of the nerve, i. e. oblique caudal ventral. About 1 centimetre dorsal to the proximal end of the ligament another branch curved away in an almost purely caudal direction. This branch is here referred to as *the descending branch*.[1] First after about 1 centimetre this branch curved back in a ventral direction, reaching or passing the ligament's distal third. In those cases where there were two medial nerves the descending branch usually arose from the lower. The descending branch always ran at a comfortable distance from where the loading thread had been passed round the middle of the ligament. It can be described as avoiding the bursa which lies between the ligament and the semimembranosus tendon (cf. Fig. 1 b). In some cases it was noticed that twigs from the descending branch bent back after reaching the ligament and ran parallel to it in a cranial direction (e. g. G and H in Fig. 7). It was occasionally possible to follow fine nerve twigs right up to where they entered the ligament.

The *posterior nerve* gave rise to branches that accompanied the upper and lower medial genicular arteries (Fig. 8). Proceeding ventrally these two arteries pass proximal and distal

[1] Skoglund (1956) noticed this branch but did not describe its course in relation to the ligament.

Fig. 8. Schematic drawing of the medial aspect of the knee joint showing the course of the branches of the medial and posterior nerves in relation to the medial collateral ligament. The muscle nerves of the medial and lateral parts of sartorius and of vastus medialis are also indicated. The tibial part of semimembranosus is severed to show the branching of the posterior nerve.

respectively to that part of semimembranosus which inserts on the tibia. In no case was it possible to follow the branch that accompanied the upper medial genicular artery as far as the ligament. Nevertheless, this branch is assumed to have transmitted the impulses obtained during probing of the ligament at the level of the joint line. In 4 out of the 6 cases investigated it was possible to follow the branch which accompanied the lower medial genicular artery until it reached (1 case) or together with the artery passed the ligament's distal third, either superficial to it (2 cases) or deep (1 case, cf. Fig. 8).

DISCUSSION

In the present investigation, the impulse recordings from the medial and posterior articular nerves during increase in tension in the ligament, the studies of innervation fields by probing and the anatomical dissections together provide strong evidence that the posterior as well as the medial nerve may contain afferent fibres from the ligament. The results also show that afferent nerve fibres coming from the ligament via either nerve run only very slight risk of being damaged by the present method of applying a loading thread round the ligament's intermediate part.

It is possible that the ligament is innervated by muscle nerves as well but this has not been shown. GARDNER (1944) found that the nerve of sartorius has two branches to the knee joint, one which "first becomes inferior to the medial tibial condyle, then turns up and anteriorly to enter the sartorius aponeurosis" and one which leaves "the sartorius at the level of the medial femoral condyle". In view of the course of these nerve branches it is likely that any afferent nerve fibres that may come from the ligament via sartorius are also unharmed by the slight dissection required for application of the loading thread.

If, however, the ligament is severed distally for longitudinal loading, an important part of its innervation may be destroyed. The descending branch of the medial nerve as well as that branch from the posterior nerve which accompanies the lower

medial genicular artery may be damaged either during the dissection or when a loading thread is tied to the detached part of the ligament. Another disadvantage of this method is the difficulty of attaching the thread sufficiently firmly to permit relatively heavy loading of the ligament. Loads greater than 200 g have not been reported to date (ANDREW and DODT 1953, ANDREW 1954).

Abduction at the joint is the most natural method for increasing the tension in the ligament and involves no dissectional damage to the ligament's innervation. It does, however, involve stretching other structures that may be equipped with stretch receptors. The reflex muscular response which was sometimes obtained when this method was tried in the present study could usually be elicited even when the ligament had been severed; it was thus clear that at least a considerable part of the response emanated from receptors located outside the ligament. The part played in the response by receptors within the ligament could therefore not be judged.

The tendon organs of Golgi have been accepted as "tension recorders *par excellence*" (FULTON 1949). The medial collateral ligament of the knee joint in the cat is equipped with receptors of a very similar type (ANDREW 1954, SKOGLUND 1956). Their fibres belong to the largest of those constituting the fibre spectra of the articular nerves (cf. SKOGLUND 1956). It is thus reasonable to assume that some of the fibres which fired while the tension in the ligament was being increased were among the largest in those nerves from which recordings were made. Evidence supporting this assumption was obtained when the size of the largest action potentials induced during the increase in tension in the ligament was compared with the size of those recorded when different parts of the ventromedial region of the joint was probed with a glass rod. In one case, while the tension in the ligament was progressively increased to about 1 kilopond, there seemed to be only one fibre firing, at an increasing rate, in the lower medial nerve. This observation agrees with ANDREW's (1954) statement that only a few Golgi-type endings are found in the ligament.

In 2 of the 35 cats there was no increase in the impulse dis-

charge in the medial nerve when the ligament was loaded transversely. This does not necessarily mean that the increase in tension was not signalled. It is still possible for this to have happened via other nerves. In these two cases impulse responses were obtained in the medial nerve on probing the tissues which cover and surround the ligament's proximal part. Since in spite of this no impulses at all were evoked in the medial nerve on transverse loading of the ligament, it may be concluded that this way of increasing the ligament's tension did not, in these two cases, involve any supraliminal stimulation of extra-ligamentary receptors sending their impulses through the medial nerve. In the cases where increased discharge was obtained in the medial and posterior nerves during transverse loading of the ligament, it could not be said with certainty that extra-ligamentary receptors were not at least partly responsible for the effect. The same source of error has also to be reckoned with in the experiments by previous authors who have loaded the ligament longitudinally. Nevertheless, it is highly probable that at least a large part of the impulse response during both transverse and longitudinal loading does, in effect, emanate from receptors within the ligament. What is certain is that transverse loading of the ligament, according to the method described, produces a large increase in the ligament's tension and that the afferent impulse flow from the knee joint is then as a rule increased, often very considerably. A study of whether or not these impulses induce reflex motor effects constituted one way of testing the hypothesis of ligamento-muscular protective reflexes. The results of such a study will be published in another paper (ANDERSSON and STENER 1959).

SUMMARY

During an investigation into the part played by ligamentary receptors in the triggering of muscular protection of joints, the need arose for a method of bringing about a large increase in tension in a ligament of an experimental animal without preparatory dissection that might result in damage to afferent

nerve fibres from the ligament. Such a method was developed using the medial collateral ligament of the knee joint of the cat. A thread was passed round the ligament's intermediate part via the bursa lying between the ligament and the tibial tendon of semimembranosus. By means of this thread the ligament was loaded transversely to the line of the leg.

That the method used did not involve any appreciable damage to the innervation of the ligament was shown a) by recording action potentials in the medial and posterior articular nerves while increasing the tension in the ligament, b) by probing different parts of the ligament with a glass rod while recording action potentials in these nerves and c) by using a dissecting microscope to follow the course of the branches of these nerves in relation to the ligament.

It was not possible to determine with certainty the degree to which extra-ligamentary receptors may have contributed to the impulse response that was obtained in the medial and posterior nerves during transverse loading of the ligament. Nevertheless, it was in all probability ligamentary receptors which were the essential source of this response in most cases.

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FROM THE DEPARTMENT OF PHYSIOLOGY, UNIVERSITY OF GÖTEBORG, GÖTEBORG, SWEDEN.

EXPERIMENTAL EVALUATION OF THE HYPOTHESIS OF LIGAMENTO-MUSCULAR PROTECTIVE REFLEXES

II. A study in cat using the medial collateral ligament of the knee joint

By

SVEN ANDERSSON AND BERTIL STENER

ABSTRACT

ANDERSSON, S. and B. STENER. Experimental evaluation of the hypothesis of ligamento-muscular protective reflexes. II. A study in cat using the medial collateral ligament of the knee joint. *Acta physiol. scand.* 1959. *48*. Suppl. 166. 27—49. — A method has been developed for effecting a large increase in the ligament's tension, without appreciably damaging its innervation during the preparatory dissection (STENER 1959). The effect of the intense afferent impulse flow, induced by this method, on motoneurones supplying muscles capable of opposing an increase in tension in the ligament was studied by myography, electromyography and monosynaptic testing. With none of these methods was it possible to detect any reflex motor effects ascribable to receptors in the ligament. On the other hand, strong reflex motor responses were obtained by gentle mechanical stimulation of extra-ligamentary receptors within the ventromedial region of the joint (skin removed).

While evaluating the hypothesis of ligamento-muscular protective reflexes, a method has been developed for effecting a large increase in tension in the medial collateral ligament of the knee joint of the cat without appreciably damaging the innervation of the ligament during the preparatory dissection (STENER 1959). A thread is passed round the middle of the ligament via the bursa lying between the ligament and the tibial tendon of semimembranosus. By means of this thread the ligament is loaded transversely to the line of the leg. As a rule during such stimulation a considerable afferent impulse discharge is induced. In the present article an account is given of the results of studies concerning the effect of these impulses on the motor side.

According to the hypothesis to be tested, articular ligaments do not act only as purely mechanical obstacles to abnormal movements of a joint; instead it has been assumed that they have as a most important task the initiation, via tension receptors, of a reflex contraction of the muscles capable of opposing the abnormal movement (for references see STENER 1959). Beyond a few degrees, abduction at the knee joint is mechanically checked by the medial collateral ligament. Any reflex motor response that may be elicited by stimulating tension receptors in this ligament should therefore be looked for first in those muscles which can oppose abduction at the joint. For a muscle to do this it must pass the joint line medial to the fulcrum for abduction, presumed to be where the lateral condyles of the femur and the tibia press against each other during abduction. Medial to this fulcrum run not only semitendinosus, gracilis, the medial part of sartorius, the tibial part of semimembranosus and the medial head of gastrocnemius (cf. Fig. 1), but also the muscles inserting on the tibia via the patellar ligament, i. e. quadriceps and the lateral part of sartorius. It is true that the lever is small for muscle forces opposing abduction via the patellar ligament, but, quadriceps being a strong muscle, the effect may nevertheless be considerable. Vastus medialis, like the lateral part of sartorius, also inserts on the tibia via the 'medial patellar ligament', and through this tendon it has a somewhat longer lever for opposing abduction than have the

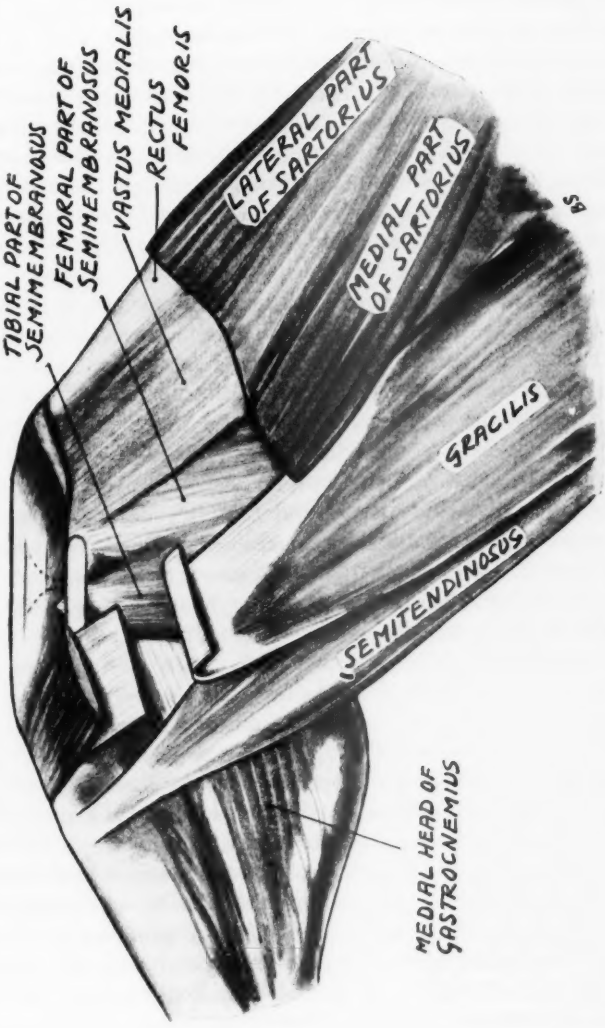


Fig. 1. Medial aspect of the right knee of the cat.

other heads of quadriceps. There is yet another reason for assuming that quadriceps in its entirety is engaged in opposing abduction, i. e. as an extensor for the knee joint. The knee flexors able to oppose abduction must be balanced by knee extensors if the effect is to be a pure opposition to abduction, and not a flexion in the joint. Thus such reflex motor responses as may be elicited by increasing the tension in the medial collateral ligament should be looked for in all the muscles shown in Fig. 1 with the exception of the femoral part of semimembranosus and with the addition of the other heads of quadriceps.

Afferent nerve fibres from the knee joint of the cat run in special articular nerves as well as in muscle nerves. Thus it is known that the nerves to sartorius and quadriceps take part in the innervation of the knee joint (GARDNER 1944). That this is also true of the nerves to other muscles which pass the knee joint has not been shown, but such a possibility cannot be excluded. In order to avoid, as far as possible, such damage to afferent nerve fibres from the medial collateral ligament as the severance of muscles or muscle nerves might involve, only those muscles which insert far away from the ligament were chosen for myography and monosynaptic testing. All the muscles could be used in electromyography.

METHODS

The method previously described (STENER 1959), for transverse loading of the medial collateral ligament of the knee joint of the cat, was used in experiments on 49 adult cats, both knee joints being used in 12 animals. After ligation of the carotid arteries decerebration, pre- or intercollicularly, was performed under ether on all the animals, usually by suction. As a rule an intravenous infusion of dextran was given after the decerebration. The animals were placed on a heated table and the rectal temperature was controlled. Drying out and cooling of exposed tissues were prevented by the use of Ringer solution at 37° C and heating lamps. The effect on the motor side

of loading the ligament was not tested until about 2 hours after administration of the ether had been discontinued.

The first experiments with myography and electromyography were carried out using instrumental fixation for the femur only. The tibia was held by one hand at the same time as the thread round the ligament was loaded by the other. In order to avoid the source of error of afferent impulses induced by the grip of the hand round the lower leg, the sciatic and saphenus nerves were severed, the latter distal to its junction with the medial articular nerve. For manual loading of the thread, a force of at least 2 kp[1] was usually used (judged approximately by comparison, using a spring balance). In some cases a momentary increase in the ligament's tension was produced by jerking the thread.

In the majority of the 49 cases all the nerves were left intact and the thread round the ligament was loaded with known weights after both the femur and the tibia had been immobilized by clamps (for a detailed description of the technique see STENER 1959). Weights of 1 or 2 kg were usually used. In order to produce a rapid increase in the ligament's tension, the following procedure was adopted. The weights attached to the loading thread were first supported so that the thread, carried over a pulley, was taut but not tense. The support was then quickly withdrawn. The tension produced in the ligament could be approximately calculated at the end of the experiment by measuring the angle between the proximal and the distal parts of the ligament during loading. In 6 cases the tensile strength of the ligament was determined by longitudinal loading. In these cases it was thus possible to compare the tension produced in the ligament during the experiment with the ligament's maximum tensile force.

Three different methods were used to study the effect on the motor side of increasing the tension in the ligament: myography (MG), electromyography (EMG) and monosynaptic testing.

A) *Myography:* Vastus lateralis and rectus femoris were severed at the patella. These muscles were isolated as far in

[1] Kilopond (kp) is used in the present work as a unit of force. 1 kp = 1 kilogram force.

a proximal direction as was possible without incurring any risk of damage to their own or neighbouring muscles' innervation. The distal ends of the cut muscles were joined via a thread to a myograph. In some cases only vastus lateralis was in fact used for myography, as the proximal attachment of rectus had been severed in order to eliminate the effect of possible movements of the pelvis on the myography. In these cases EMG was carried out in rectus at the same time as the myography.

B) *Electromyography:* This method was used to study the muscle activity in quadriceps (particularly rectus and vastus medialis, occasionally vastus intermedius), sartorius (both the lateral and medial part), gracilis, semitendinosus, semimembranosus (the part which inserts on the tibia) and the medial head of gastrocnemius. Bipolar needle electrodes of silver were used, insulated except at their tips and connected to a cathode-ray oscillograph via an AC-amplifier. Records were made on moving bromid paper.

C) *Monosynaptic testing:* (Fig. 2) After lumbosacral laminectomy the ventral roots L 6—S 1 (sometimes L 5 and S 2 as well) were severed ipsilateral to the ligament being loaded. Only those muscles were suitable for monosynaptic testing which, in addition to their ability to oppose abduction at the knee joint, also insert far away from the medial collateral ligament. The knee extensors vastus lateralis and rectus and the knee flexor semitendinosus (in some cases together with biceps) were used. The nerves to these muscles were severed as far distal as possible and placed on pairs of stimulating silver electrodes in paraffin pools at 37° C. Usually one test shock was given per sec. The monosynaptic potentials elicited were led off, in a paraffin pool at 37° C, from the severed ventral roots by bipolar silver electrodes connected to a cathode-ray oscillograph via an AC-amplifier. As a rule the animals were curarized.

Regardless of the method and the muscle used for studying the effect on the motor side of increasing the ligament's tension, the reflex excitability was checked before and after each loading of the ligament. In the case of extensors the contralateral foot was often stimulated in such a way that a crossed extension

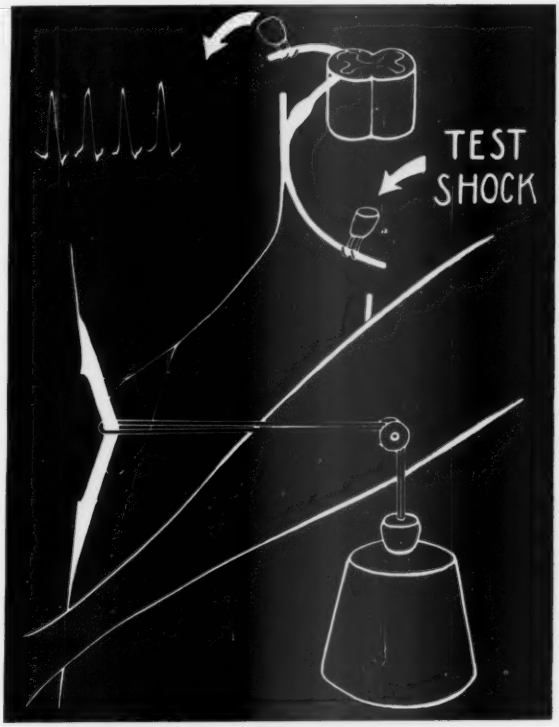


Fig. 2. Diagram of the method for monosynaptic testing.

reflex was elicited. A similar stimulation of the ipsilateral foot could usually be used for checking the reflex excitability of flexors. In many cases use was made of HAGBARTH's (1952) finding that extensor muscles can be "excited from a skin area mainly localized over the muscle itself". HUNT and PAINTAL (1958) found that an increase in the reflex discharge of γ-motoneurones of the medial head of gastrocnemius could be elicited by "merely grasping the tendo Achillis between the fingers". The same type of stimulation was sometimes used in the present work for eliciting α-activity in this muscle. In

most cases reflex motor activity could be induced as a test of the reflex excitability by applying a light pressure to certain points within the ventromedial region of the joint. The skin over this region of the joint had been removed.

In many cases, when the effect on the motor side of loading the ligament had been tested, the experiment was completed by impulse recording from the medial articular nerve and sometimes from the posterior nerve too (for the technique see STENER 1959). In this way it was possible to demonstrate at least part of the afferent impulse flow induced during loading of the ligament.

RESULTS

Myography and electromyography

Successful experiments with these methods were made in 39 cats. Myography alone was done in 12 animals (16 legs). Electromyography was used in 27 animals (35 legs). EMG and MG were combined in 15 animals.

In all 39 experiments (51 legs) the results were the same in principle, i. e. no reflex muscular responses ascribable to ligamentary receptors were obtained on transverse loading of the ligament, whereas in every case control reflexes could be elicited.

During the experiments with *myography* alone (as well as in a number of the EMG experiments) the tension of the ligament was increased by pulling the loading thread by hand. The counter-forces acted partly via the clamping arm immobilizing the femur and partly via the hand gripping the tibia. The very slight deflection of the curve, in either direction, which sometimes occurred was produced mechanically due, among other things, to the difficulty of achieving a perfect balance between the pull and the counter-forces. No reflex motor responses could be registered with EMG in the muscles that were connected to the myograph. Neither could any reflex activity ascribable to ligamentary receptors be observed when a momentary increase in the ligament's tension was produced by jerking the loading thread. On the other hand, intense reflex muscular

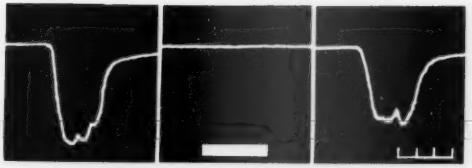


Fig. 3. Cat 1.6 kg. Decerebrate. MG. Vastus lateralis. A and C: control before and after loading of the ligament respectively. Response was obtained on plantar flexion of the toes of the contralateral foot. B: transverse loading of the ligament using a weight of 2 kg (signal line) resulting in an approximate tension in the ligament of 3 kp. Time 1 sec.

activity was induced by pinching the skin of the ventral aspect of the thigh or by lightly probing different parts of the ventromedial region of the joint, which had been stripped of skin (see below).

When the series of experiments with *electromyography* was begun, the primary object was to study the effect of loading the ligament on the activity in sartorius. Both the lateral and the medial part of this muscle were tested regularly. During the early experiments with EMG (sometimes in combination with MG) vastus medialis and rectus were usually tested as well. Later the investigation was extended to include other muscles capable of opposing abduction at the joint.

In each animal of a series of 10 the following muscles were tested with EMG (cf. Fig. 1): rectus, vastus medialis, the lateral and medial parts of sartorius, gracilis, semitendinosus, semimembranosus (the part inserting on the tibia) and the medial head of gastrocnemius. In addition vastus lateralis was tested with MG in 4 of these cases (rectus, which was connected to the myograph, had been severed proximally). In these 4 cases a weight of 2 kg was used for loading the ligament, in 5 of the other 6 cases 1 kg was used and in the remaining case 0.4 kg.

Figs. 3, 4, 5 and 7 are taken from a single animal in this series. Fig. 3 shows the result of *myography*. Before and after loading of the ligament (A and C) contraction of vastus lateralis

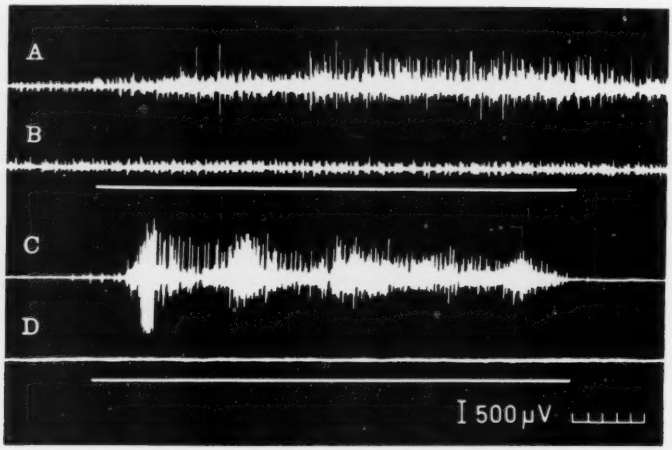


Fig. 4. Cat 1.6. Decerebrate. EMG. A: vastus medialis. First background discharge, followed by response on plantar flexion of the toes of the contralateral foot. B: vastus medialis. The background discharge did not change during transverse loading of the ligament using a weight of 2 kg (signal line). C: semitendinosus. Response on lightly gripping the ipsilateral foot with the fingers. D: semitendinosus. No response on transverse loading of the ligament using a weight of 2 kg (signal line). The same effect as in A and C could be elicited after B and D respectively. Time 0.1 sec.

could be regularly induced by plantar flexion of the toes of the contralateral foot. The thread round the ligament was loaded for 3 sec. (B, signal line) using a weight of 2 kg. No deflection of the curve was induced, even though the myograph had been set to provide large amplification. The ligament was loaded several times, each time with the same result.

Fig. 4 shows the results of *electromyography* in vastus medialis and semitendinosus. Prior to loading the ligament activity could easily be evoked in these muscles, in vastus medialis (A) by plantar flexion of the toes of the contralateral foot, and in semitendinosus (C) by lightly gripping the ipsilateral foot between the fingers. When the thread round the ligament was loaded for 3 sec. (B and D, signal lines) using a weight of 2 kg,

no effect was noticed on the background discharge in vastus medialis (B), nor was any activity evoked in semitendinosus (D). After loading of the ligament the reflex excitability was checked using the same stimulation and with the same result as before. EMG was used in a similar way to study the effect of loading the ligament on the activity in the other muscles capable of opposing abduction at the knee joint. No activity was evoked in any of these muscles when the thread was loaded using a weight of 2 kg. As a check before and after every loading of the ligament, activity was evoked in knee extensors by lightly gripping the contralateral foot between the fingers, and in knee flexors by a similar stimulation of the ipsilateral foot. Reflex activity in the lateral part of sartorius was thus evoked by contralateral and in the medial part by ipsilateral stimulation (cf. SHERRINGTON 1910). In the medial head of gastrocnemius control reflexes were elicited by grasping the Achilles tendon between the fingers. A very slight pressure applied with a glass rod to certain points within the ventromedial region of the joint (Fig. 7) consistently elicited reflex responses in the isolated rectus and in vastus medialis.

In order to assess the afferent impulse discharge induced during loading of the ligament, the medial and posterior articular nerves were dissected free and cut off for recording from their peripheral stumps. Fig. 5 shows results from such recordings. In both the upper (B) and the lower (A) medial nerves, as well as in the posterior nerve (C) the discharge was increased when the thread round the ligament was loaded using a weight of 2 kg. The increase in discharge was particularly large in the lower medial nerve (A).

It was calculated that the tension in the ligament had increased to approximately 3 kp when a weight of 2 kg had been hung on the loading thread. The ligament ruptured under a longitudinal load of 9 kp, which means that the tension produced during the experiment corresponded to a third of the ligament's tensile strength.

In one experiment in this series, loading of the ligament using a weight of 2 kg evoked reflex motor activity in vastus lateralis, rectus, vastus medialis and the lateral part of sartorius (i. e.

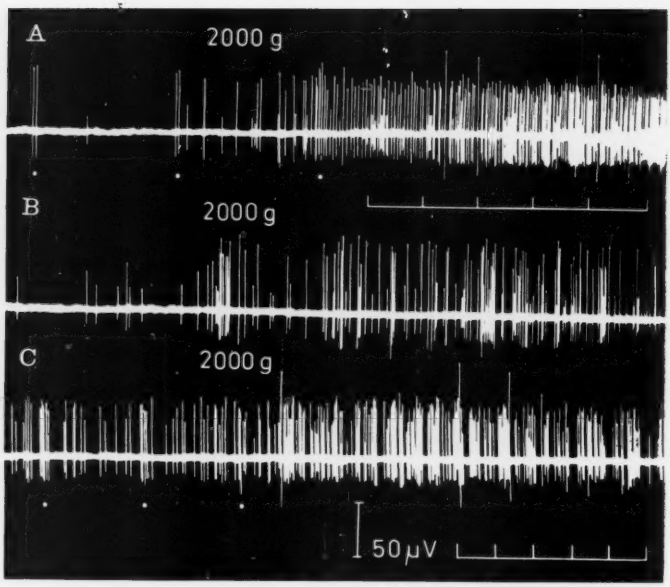


Fig. 5. Cat 1.6 kg. Decerebrate. Same animal as in Figs. 3 and 4. Recordings from the medial and posterior articular nerves *after* MG and EMG. A: the lower medial nerve. B: the upper medial nerve. C: the posterior nerve. The dots under A and C indicate action potentials synchronized with the pulse. When the ligament was transversely loaded using a weight of 2 kg its tension was calculated to be 3 kp. Time 0.1 sec. N.B. Faster film speed in A than in B and C.

knee extensors), but not in any of the knee flexors. However, it was noticed that in this case motor activity was consistently induced in the knee extensors when a glass rod was gently pressed against two different points, located just outside the ventral edge of the ligament's proximal part. Pressure on the ligament itself, on the other hand, did not result in any reflex motor effect. There was therefore reason to assume that the motor effect induced in this case in the knee extensors on loading the ligament was due to stimulation of extra-ligamentary receptors. In the other experiments, loading of the ligament

did not result in any effect on the motor activity in any of the muscles tested. Before and after loading of the ligament control reflexes were elicited as in the experiment illustrated.

In 5 animals, when the effect on the motor side of loading the ligament had been tested, the medial and posterior nerves were dissected free for recording of afferent impulse discharge induced during loading of the ligament. An increased discharge was obtained in both nerves in 4 of these animals, but only in the medial nerve in the fifth. In the other 5 experiments with testing of all muscles capable of opposing abduction at the knee joint, and in 8 further EMG experiments, recordings were made from the medial nerve only. In 11 of these 13 cases (4 out of the 5 and 7 out of the 8) an increased discharge was obtained in the nerve when the ligament was loaded.

Monosynaptic testing

Successful recordings with this method were obtained in 10 cats. A monosynaptic reflex which could be used for testing the effect on the motor side of loading the ligament was obtained in 9 animals by the stimulation of nerves to knee flexors (semitendinosus, in 3 cases biceps as well), and in 5 animals by the stimulation of nerves to knee extensors (vastus lateralis and rectus). In 4 of the experiments monosynaptic reflexes, suitable for testing, were obtained by the stimulation of nerves to knee flexors[1] and extensors in the same animal.

Fig. 6 illustrates an experiment of the last-mentioned type (case no 2 in Table I). The cat showed good reflex excitability after the effects of the ether had worn off. Before testing it was curarized to the point where no muscle contractions could be seen when the severed nerves were stimulated. When the thread round the ligament was loaded for 9 sec. (signal lines) using a weight of 2 kg no effect was observed on the size of the monosynaptic potential in either A (vastus lateralis and rectus — L 6) or B (semitendinosus — S 1). The reflex excitability was checked both before and after the loading. Unquestionable excitatory and inhibitory effects could be induced even with

[1] In these 4 cases semitendinosus was the only flexor used.

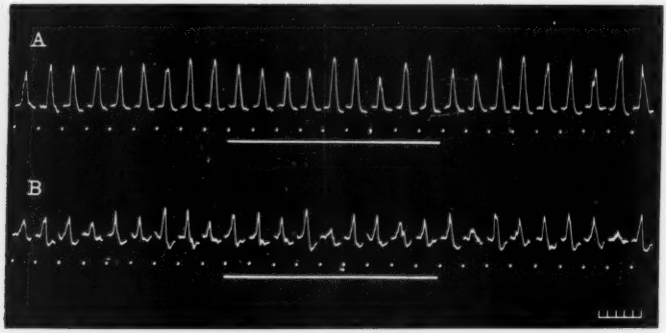


Fig. 6. Cat 2.8 kg. Decerebrate. Curarized. Monosynaptic testing. A: vastus lateralis and rectus — L 6. B: semitendinosus — S 1. One shock per sec. Signal line = transverse loading of the ligament using a weight of 2 kg, corresponding to a tension in the ligament of approx. 3.4 kp. Time 1 sec., dots (1 msec. to the right below).

weak stimuli (manipulations of the ipsilateral foot). Repeated loadings using weights of 1 and 2 kg were made without any noticeable effect on the monosynaptic potential. The result was the same if, instead of one test shock per sec. (as in Fig. 6), a higher stimulation frequency was used (up to 10 per sec.). Recordings from the medial nerve after completion of the testing showed that transverse loading of the ligament using weights of 1 and 2 kg gave rise to a strong afferent impulse flow. It was calculated that a weight of 2 kg produced a tension of approximately 3.4 kp in the ligament.

The other 9 experiments with monosynaptic testing gave similar results. When the ligament was loaded, using weights of 1 to 2 kg, no effect in response to stimulation of ligamentary receptors was observed on the size of the monosynaptic potential; control stimuli, on the other hand, induced an effect in every case. In order to test the possibility of influencing the monosynaptic potential various methods were used, before and after loading of the ligament, for stimulating the ipsi- or contralateral foot (touching lightly, pressing, pinching, bending the toes etc.). During some experiments (e. g. case no 4 in Table I),

while eliciting the monosynaptic reflex of the extensors, it was observed that a very strong excitatory effect could be induced by taking a light hold of the contralateral thigh (barely touching the skin), whereas a firmer grip resulted in almost complete inhibition. When the grip was released again the excitatory effect reappeared for the moment when the fingers were once more just touching the skin.

At the end of 8 of the 10 experiments with monosynaptic testing, recordings were made from the medial nerve and in every case the discharge in the nerve increased when the ligament was loaded transversely using weights of 1 to 2 kg.

In the 5 cases in Table I the angle between the ligament's proximal and distal parts during loading was measured in order to arrive at an estimation of the tension produced. The ligament's tensile strength was determined in 3 cases so that the relation between this and the tension produced could be calculated (right-hand column). In cases 2, 3 and 4 monosynaptic test reflexes were elicited from extensor and flexor muscle nerves in the same animal. In all 5 cases recordings were made from the medial nerve (see above). Confirmed afferent impulse discharge, induced while loading the ligament, thus had no noticeable effect on the monosynaptic potentials of either extensor or flexor muscles, though even weak control stimuli clearly had such an effect.

TABLE I

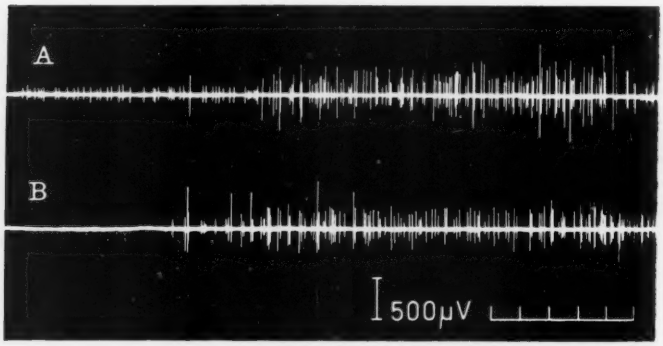
No	Body weight of the cat (kg)	Weight (kg) used for loading the ligament	Tension (kp) produced in the ligament	Effect on the monosynaptic potential of loading the ligament	Increased discharge in the medial nerve on loading the ligament	Relation between the tension produced and the tensile strength of the ligament
1	1.5	1	1.9	0	+	38 %
2[1]	2.8	2	3.4	0	+	
3	1.8	2	3.9	0	+	55 %
4	1.5	2	3.9	0	+	65 %
5	2.8	2	3.7	0	+	

[1] cf. Fig. 6.

Reflex motor response during stimulation of extra-ligamentary receptors within the ventromedial region of the knee joint

Already during the initial experiments, when only myography (vastus lateralis and rectus) was used for testing the effect on the motor side of loading the ligament, it was noticed that strong reflex muscular responses could be induced by probing the patellar ligament, the medial aspect of the femur's distal and the tibia's proximal end, and the medial joint line. Only the skin covering these parts of the joint had been removed (cf. Fig. 9). After some experiments it was clear that the responses could only be elicited from certain points, the number and location of which varied from animal to animal. An extremely slight pressure on these points was often sufficient to produce a large deflection of the curve.

These observations were confirmed when the experiments using electrophysiological techniques were carried out. Fig. 7 shows electromyographic recording of reflex muscular response



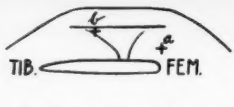


Fig. 7. Cat. Decerebrate. EMG. A: vastus medialis. First background discharge, followed by response during light probing with a glass rod at the point 'a' in the diagram showing the ventromedial region of the joint. B: rectus femoris (severed at both ends). Response during probing at the point 'b'. Time 0.1 sec.

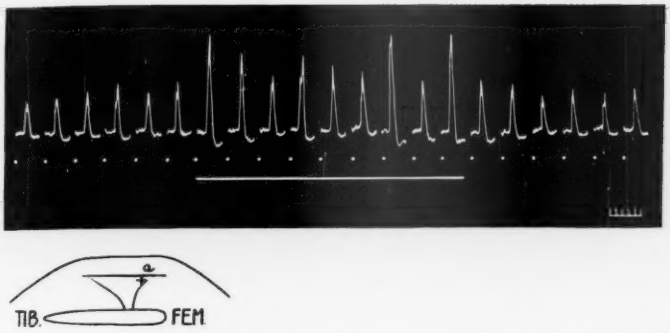


Fig. 8. Cat. Decerebrate. Monosynaptic testing. Vastus lateralis and rectus — L 6. One shock per sec. Signal line = light probing with a glass rod at the point 'a' within the ventromedial region of the joint. Time 1 sec., dots (1 msec. to the right below).

in vastus medialis (A) and in rectus (B) evoked by lightly pressing with a glass rod against two points within the ventromedial region of the joint (a and b in the diagram). Rectus had been severed both proximally and distally. Fig. 8 shows a clear facilitatory effect on the monosynaptic potential of vastus lateralis and rectus during slight pressure with a glass rod (signal line) against a point located in the angle between the femoral condyle and the patellar ligament.

As a rule an excitatory effect was obtained in knee extensors. As to knee flexors, the investigation was not sufficiently systematic for definite conclusions. In 4 cases EMG response was obtained in the lateral part of sartorius but not in the medial; in 3 other cases activity was evoked in both parts.

Fig. 9 illustrates an experiment where the entire ventromedial region of the joint was subjected to systematic probing with a glass rod (millimetre by millimetre). The reflex muscular response elicited was recorded by electromyography in rectus. Both the femur and the tibia had been immobilized. A strong EMG response was consistently obtained when only a very slight pressure was applied to the 18 points marked, whereas the same type of stimulation at other points had no effect.

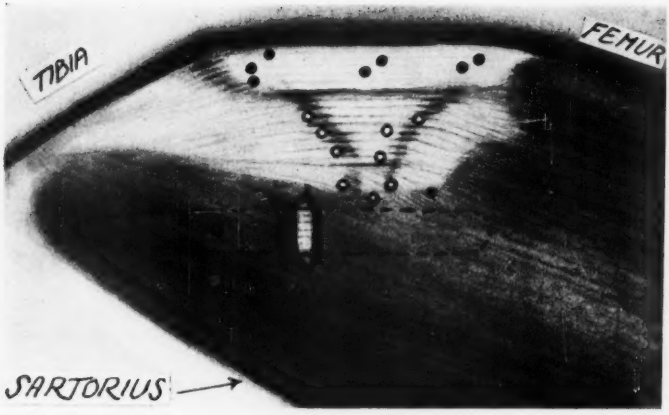


Fig. 9. Cat. Decerebrate. Systematic probing, millimetre by millimetre, of the ventromedial region of the joint, using very light pressure with a glass rod. A reflex motor response, recorded with EMG in rectus, was consistently obtained during pressure against each of the 18 points marked. After the medial articular nerve had been severed, response was obtained only during pressure at the points marked by filled circles.

After the medial articular nerve had been severed a response could be elicited only by stimulation at the points indicated by the filled circles. Four more experiments of this type were performed and in every case it was found that a number of points within the innervation field of the medial nerve were silenced by severance of this nerve, whereas stimulation at other points resulted in response as easily afterwards as before.

DISCUSSION

The results obtained in this study on decerebrate cat do not agree with the hypothesis of ligamento-muscular protective reflexes put forward in the literature. When the tension in the medial collateral ligament of the knee joint was strongly increased, no reflex effects ascribable to ligamentary receptors

were obtained on motoneurones supplying muscles able to oppose an increase in tension in the ligament.

The knee joint was chosen for the experiments because it appears to be especially suitable for testing the validity of the hypothesis. Its considerable muscle support and the normally great strain on the joint would, teleologically, make a protective reflex of the proposed type especially useful.

The hypothesis presupposes the occurrence of muscle responses in extensors as well as flexors. That decerebrate animals were used ought to have been an advantage in testing the effect of loading the ligament on extensors (cf. SHERRINGTON 1910), and only an immaterial disadvantage in the case of flexors, since control reflexes were easily elicited in these muscles as well.

Another point is that decerebration naturally introduces an error if it is so that the postulated protective reflex utilizes a long cerebral arc. Supporters of the hypothesis, however, consider that the reflex utilizes a short spinal arc. But then it should be recalled that under certain conditions the interneurones of spinal reflex arcs may be tonically inhibited from supraspinal centres. ECCLES and LUNDBERG (1958 b, 1959) have shown this to be the case in decerebrate preparations for the interneurones mediating the actions of the general flexion reflex (excitatory actions in flexor motor nuclei and inhibitory actions in extensor motor nuclei). However, the hypothetic reflex of the present study would not be part of the general flexion reflex, because its effect is presupposed to be a pure opposition to abduction and not a flexion of the joint. Besides, in a study carried out on man with no anaesthetization at all (PETERSÉN and STENER 1959), and hence with the central nervous system intact, the results in respect of the hypothesis tested completely agreed with those presented in this paper.

The size of the monosynaptic potential (ECCLES and PRITCHARD 1937), elicited from a muscle nerve and recorded from a ventral root, may be used as a test of the effect of afferent nerve impulses on the excitability of motoneurones (RENSHAW 1940, LLOYD 1943 a and b, 1946). Relatively few experiments were made with monosynaptic testing but the results were uniform and in full accordance with those obtained with MG

and EMG, which do not involve severance of the external loop through the muscle.

That transverse loading of the ligament was used for increasing its tension should not affect the issue because, according to the hypothesis, the afferent impulses of the reflex are emitted from tension receptors located within the ligament. The receptors assumed to be engaged in the reflex were thus adequately stimulated. In the study on man mentioned above, the increase in tension in the same ligament was produced in a completely natural way by forcibly attempting abduction at the joint. The increase in tension applied to the ligament, both in cat and man, was so strong that it can be stated that the ligament acted as a definite mechanical check to abduction at the joint; yet no reflex activity was observed in the muscles capable of opposing abduction.

One way of eliciting control reflexes was by gentle pressure against certain points within the ventromedial region of the joint (skin removed). For several reasons it was clear that these reflexes were not myotatic. Very gentle pressure against a certain point consistently evoked reflex muscular response, whereas pressure against the *same* tendon fibres proximal or distal to this point evoked no response. The fact that a number of points were silenced by severance of the medial nerve provided additional evidence that the muscle response originated in local receptors. Further investigations are needed in order to determine the type of these receptors and their exact location in relation to the different layers of tissue.

Eccles and Lundberg's (1958 a) finding that semimembranosus, a hip extensor, receives I a excitatory action from the knee flexors semitendinosus and gracilis is of interest because one part of semimembranosus, like these knee flexors, inserts on the tibia — a fact not observed by either these authors or Sherrington (1910) in his basic work on limb reflexes.

In 49 animals, with one possible exception (for the knee extensors), a strong increase in tension in the ligament did not induce any noticeable reflex motor effects, whereas control reflexes were evoked in all the experiments, in most cases even with very weak stimuli. In the one exception there was every reason to

suppose that the activity evoked was in fact induced by extra-ligamentary receptors. In 26 animals, after testing the effect on the motor side of loading the ligament, recordings were made from the medial articular nerve. In 24 of these animals increased discharge was obtained in the medial nerve on loading the ligament. In the remaining 2 cases the increase in tension was probably signalled via other nerves. In 19 of the 49 animals (in the early experiments) the sciatic nerve was severed. This may have destroyed some afferent nerve fibres from the ligament (STENER 1959), but it is highly probable that the loading of the ligament was none the less signalled to the central nervous system via the medial nerve or via muscle nerves.

The question naturally arises as to what task is performed by the often very intense afferent impulse activity induced during loading of the ligament. SKOGLUND (1956) pointed out that the tension recording receptors found in the ligament by him and ANDREW (1954) "should be the true position receptors". This opinion fits our finding that these receptors in the ligament seem to serve other purposes than activating a reflex muscular protection for the joint.

SUMMARY

The hypothesis of ligamento-muscular protective reflexes put forward in the literature was tested on 49 decerebrate cats, using the medial collateral ligament of the knee joint.

A strong increase in tension was applied to the ligament, and the effect on the motor side of such stimulation was studied by myography, electromyography and monosynaptic testing. All muscles able to oppose an increase in tension in the ligament were tested. With none of the methods and in none of the muscles was it possible to detect any reflex motor effects in response to the increase in tension in the ligament, although control reflexes could be elicited. That the absence of reflex motor effects was not due to absence of afferent discharge could be shown, at the end of the experiment, by recording action potentials from the medial and posterior articular nerves while increasing the tension in the ligament.

The results are not in accord with the hypothesis that the release of muscular protection of joints is triggered from tension receptors located in ligaments.

One way of eliciting control reflexes was by gentle mechanical stimulation of extra-ligamentary receptors within the ventro-medial region of the joint (skin removed). Further experiments are necessary for determining the type and exact location of these receptors and their reflex actions.

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FROM THE DEPARTMENT OF CLINICAL NEUROPHYSIOLOGY, SAHLGRENSKA SJUKHUSET, GÖTEBORG, SWEDEN.

EXPERIMENTAL EVALUATION OF THE HYPOTHESIS OF LIGAMENTO-MUSCULAR PROTECTIVE REFLEXES

III. A study in man using the medial collateral ligament of the knee joint

By

INGEMAR PETERSÉN AND BERTIL STENER

ABSTRACT

PETERSÉN, I. and B. STENER. Experimental evaluation of the hypothesis of ligamento-muscular protective reflexes. III. A study in man using the medial collateral ligament of the knee joint. *Acta physiol. scand.* 1959. *48.* Suppl. 166. 51—61. — The tension in the ligament was increased in a natural way by forcibly trying to abduct the tibia on the femur. During such stimulation the motor activity in sartorius, semimembranosus and vastus medialis (i. e. in muscles capable of opposing an increase in tension in the ligament) was studied by electromyography. In 35 subjects (using 43 normal knee joints) it was never possible to detect any reflex motor effects ascribable to stimulation of receptors in the ligament. This is in close agreement with the results obtained by ANDERSSON and STENER (1959) in cat and is not in accordance with the hypothesis, put forward in the literature, that tension receptors in ligaments elicit a protective muscular reflex.

Experiments have been performed in cat to test the hypothesis of ligamento-muscular protective reflexes (STENER 1959, ANDERSSON and STENER 1959). The present paper is an account of an investigation with the same aim in view, carried out on man.

The hypothesis mentioned (for references see STENER 1959) involves the assumption that articular ligaments, instead of acting only as purely mechanical obstacles to abnormal movements of a joint, have as a most important task the initiation, via tension receptors, of a reflex contraction of the muscles capable of opposing the abnormal movement.

As in the experiments in cat the medial collateral ligament of the knee joint was chosen. Tension receptors of this ligament will presumably be stimulated during attempted abduction at the joint (Fig. 1). Then, in accordance with the hypothesis being tested, reflex muscular responses should first be sought in the muscles capable of opposing abduction at the joint. Such muscles must be all those which pass the joint line medial to the presumed fulcrum for abduction (C in Fig. 1), i. e. the pes anserinus muscles, semimembranosus, quadriceps and the medial head of gastrocnemius. Sartorius, gracilis and semitendinosus have the longest lever for opposing abduction. The lever is somewhat shorter for semimembranosus but according to KAPLAN (1957) this muscle is the most important active stabilizer of the knee joint on the medial side. A part of its tendon is contiguous to the dorsal fibres of the distal part of the medial collateral ligament (RAINAUT 1959, cf. Fig. 2). Vastus medialis is the part of quadriceps best suited to oppose abduction at the knee joint. If this muscle is severed from the patella it will be found to function, as does semimembranosus, as an active stabilizer of the joint on the medial side, i. e. via the medial patellar retinaculum, which inserts on the tibia just ventral to the distal part of the medial collateral ligament (Fig. 2).

PALMER (1958) attempted to demonstrate a ligamento-muscular reflex originating in the medial collateral ligament of the knee joint in man. He stimulated the ligament to begin with by increasing its tension using a ligature sewn through it;

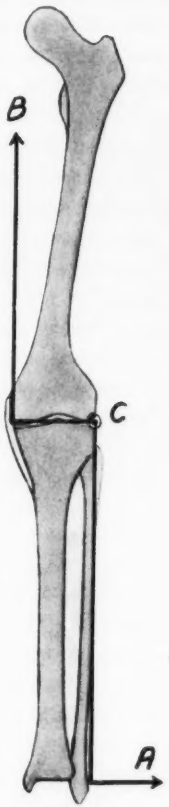

Fig. 1.

Fig. 2.

Fig. 1. Diagram showing the lever for the force A acting to abduct the tibia on the femur and for the force B representing the tension produced in the medial collateral ligament. C = fulcrum for abduction at the joint.

Fig. 2. Schematic drawing from a dissection specimen showing semimembranosus and vastus medialis as active supporters of the medial collateral ligament in lateral stabilization of the knee joint. a = the tendon of semimembranosus, b = the medial collateral ligament and c = the medial patellar retinaculum.

later he used the method of reflex taps against the ligament. During such stimulation, especially when taps were made over the 'deep portion' of the ligament, he was able to record reflex muscular responses using electromyography in semimembranosus, sartorius and vastus medialis.

In the experiments on cat mentioned above, however, it was never possible to elicit muscular reflexes ascribable to stimulation of tension receptors in the ligament, although it was possible to show that a strong afferent impulse flow was released on increasing the tension in the ligament. On the other hand, strong reflex muscular responses were easily obtained by gentle mechanical stimulation of receptors located *close to but outside* the ligament. With the stimulation technique used by PALMER it is impossible to say whether or not the reflex muscular responses obtained did in fact originate in extra-ligamentary receptors, and therefore the 'ligamento-muscular' reflex demonstrated by him cannot be accepted without further evidence.

METHODS

The material was made up of 35 subjects, aged 20 to 58 (average age 28), 4 women and 31 men, with no known injury or disease in the knee joint used in the investigation. 15 athletic students were selected. Both legs were used in 8 of these subjects. In a further 20 volunteers, the other knee joint, not included in this material, had been damaged recently or on some previous occasion. Apart from this damage all 35 of the subjects were healthy. No form of anaesthetic was used. The subjects were placed in a comfortable supine position.

An increase in the tension in the medial collateral ligament of the knee joint was produced in a natural way by forcibly trying to abduct the tibia on the femur. To do this, pressure was applied to the medial side of the ankle with one hand and to the lateral side of the knee with the other. In order to avoid ab- and adduction at the hip a constant relation had to be maintained all the time between the force applied to the ankle and the opposing force at the knee. Because of the difference

in leverage of these forces in relation to the hip the one acting on the knee had to be considerably greater. During the attempted abduction, the knee joint was supported in a position 5—10° from full extension. If the knee is held in this position and the muscles of the leg are relaxed, the primary hindrance to abduction at the joint is its medial collateral ligament; this is evident from the fact that severance of only this ligament allows a marked increase in the very slight abduction normally possible when the joint is slightly flexed (see survey by RAINAUT 1959). This fact was confirmed by dissection studies on 7 cadaveric specimens from middle-aged persons. Since the lever of the force applied to the ankle is several times greater than that by which the ligament opposes abduction, the tension produced in the ligament will be considerably larger than the force acting on the ankle (Fig. 1). After practising the technique it was possible to achieve a large increase in the tension in the ligament within the course of 1 second (checked with a stop-watch).

In a number of subjects a known force was also applied to the foot, using a tested spring balance attached, at the level of the lateral malleolus, to a strap wound round the ankle and the foot. The forcibly attempted abduction by hand alone was judged by the subjects to be equivalent to an attempted abduction using a force of 8—10 kp[1] applied to the spring balance. It was easiest for the subjects to compare the two methods if they estimated the pressure experienced on the lateral side of the knee joint during each.

The effect on the motor side during increase in the tension in the ligament was studied by *electromyography* (EMG) and to a certain extent by inspection and palpation as well. Concentric needle electrodes (ext. diam. 0.42 or 0.65 mm) were used for EMG, connected to a three-channel Disa electromyograph; recordings were made from *sartorius*, *semimembranosus* and *vastus medialis*.

Sartorius was chosen for EMG from among the three pes anserinus muscles because it can be identified more accurately

[1] Kilopond (kp) is used in the present work as a unit of force. 1 kp = 1 kilogram force.

than either of the other two. It is most easily found just distal to its origin on the pelvis. The subject raises the leg and rotates it outwards while somewhat flexing the knee joint; the muscle can then be felt as a ridge between the fingers. Semimembranosus is most easily identified about 10 centimeters proximal to the knee joint. Here the cross section of this muscle is large, whereas that of semitendinosus and of gracilis is small. The electrode was inserted just medial to the semitendinosus tendon, which can easily be palpated. In order to prevent change in the location of the electrode this was inserted with the knee joint in approximately the same position as for loading of the ligament.

Before and after testing the effect of loading the ligament on the activity in the three muscles, the reliability of the recording and the location of the electrodes were checked by voluntary contraction of each muscle.

The activity in gracilis and semitendinosus could be checked to some extent without EMG — in gracilis by carefully watching the medial aspect of the thigh and in semitendinosus by palpation of the tendon. The palpation could be carried out with the hand fulfilling the double function of applying pressure to the lateral aspect of the knee joint and supporting this with the fingers so that it was slightly flexed. Even a weak voluntary contraction of semitendinosus was sensed at once through the fingertips since these displaced the tendon ventrally when the muscle was relaxed.

Before increasing the tension in the ligament a check was made to ensure that there was no activity in the muscles used for EMG and that the other muscles of the leg were also relaxed.

RESULTS

The results were the same in principle in 34 of the 35 subjects (42 normal knee joints). No activity was observed in the muscles investigated when the tension in the medial collateral ligament was strongly increased. EMG was carried out in 30 cases in sartorius, semimembranosus and vastus medialis and in 5 cases in sartorius and vastus medialis only. In every case

Fig. 3. 25-year-old man. Unanaesthetized. Simultaneous recording by EMG in sartorius, semimembranosus and vastus medialis. A: no response in these muscles on forcibly attempting to abduct the tibia on the femur. The attempted abduction was started at the arrow. A force of 9 kp was applied to the ankle for 4 sec. (signal line). B: voluntary contraction.

the increase in tension in the ligament was produced by forcibly attempting abduction by hand. In a series of 8 cases the force acting on the ankle was also applied via a spring balance loaded with 8—10 kp.

Fig. 3 shows a case with simultaneous recording from sartorius, semimembranosus and vastus medialis. When the spring balance was loaded for 4 sec. (A, signal line) with a force of 9 kp, reached within 1 sec. after the loading had begun (↑), no activity was observed in the muscles investigated with EMG. The attempted abduction was repeated several times, each time with a negative result, even when recordings were made with a considerably increased amplification. Neither could any contractions be detected by inspection or palpation in other muscles capable of opposing abduction at the knee joint. The lever for the force applied to the foot was compared with the width of the knee joint and it was estimated that the tension produced in the ligament probably amounted to about 40 kp. After the loading of the ligament the location of the electrodes was checked by voluntary contraction of sartorius, semimembranosus and vastus medialis (Fig. 3 B). It was also ascertained that even weak voluntary contractions in the muscles of the leg could easily be perceived by inspection and palpation.

In one of the 35 subjects weak activity in sartorius (single motor unit response) was evoked to begin with when the attempted abduction was made by hand. However, activity sometimes appeared in the intervals between attempts at abduction as well. The position of the leg was then changed to one more comfortable for the subject, making it easier for him to relax the muscle completely. After this, when forcible attempts at abduction were carried out by hand and with the spring balance (8—10 kp), no activity was observed in sartorius, nor did any activity now appear between the attempts at abduction. Immediately afterwards the EMG-recording was controlled by voluntary contraction of the muscle. The other subjects had no difficulty in completely relaxing the muscles in the leg.

None of the subjects experienced any pain in spite of the large increase in the tension in the ligament.

DISCUSSION

The results obtained in this study on unanaesthetized man are in close agreement with those obtained by ANDERSSON and STENER (1959) in studies on decerebrate cat. Taken together, the results of these two investigations provide strong reasons to doubt the existence of a protective muscular reflex originating in tension receptors located in ligaments.

By means of attempted abduction at the knee joint a large increase in the tension in the medial collateral ligament could be produced without eliciting any activity, detectable with EMG, in sartorius, semimembranosus or vastus medialis and this in spite of the fact that these muscles must be especially important supporters of the ligament in lateral stabilization of the joint. Even if — against all probability — reflex activity was evoked in other muscles capable of opposing abduction at the knee joint such activity could not be perceived by inspection or palpation and cannot have produced any mechanical effect worthy of note.

If, during experiments of the type described in the present paper, activity were evoked in a muscle, it would be by no means certain that the response obtained did in fact emanate from receptors located within the ligament; many receptors located elsewhere must also be stimulated during the attempted abduction at the joint. In one of the 35 subjects a weak response was obtained in sartorius on attempted abduction at the knee when the subject, to begin with, had difficulty in completely relaxing the muscle. The origin of this response may or may not have been receptors in the ligament. In the same subject, after the position of the leg had been changed and complete relaxation of the muscle had been obtained, a strong increase in the tension in the ligament could repeatedly be produced without eliciting any response in sartorius.

It would be of interest to make an investigation of this type with a certain amount of background activity present in the muscles. But, apart from the difficulty of determining the origin of the reflex muscular response that might then be obtained, it would be hard to calculate the tension produced in

the ligament when muscles capable of lessening this tension were contracted. In corresponding experiments in the cat (ANDERSSON and STENER 1959) the increase in tension in the ligament had no appreciable effect on background activity in the muscles.

It is highly probable that tension receptors in the ligament were activated by the increase in tension used in this study on man. Tension recording receptors (Golgi-type endings) in the same ligament in the cat (ANDREW 1954, SKOGLUND 1956) emit impulses in response to considerably weaker stimulation (ANDREW 1954); a large increase in the tension in the ligament in the cat evokes an intense afferent impulse flow (STENER 1959, ANDERSSON and STENER 1959).

For a long time it has been recognized clinically that the activity of thigh muscles may be reflexly influenced by *injury* to various structures of the knee joint. Some of the subjects in the present study had recently suffered a mild injury to the medial collateral ligament of the other knee joint. The diagnosis was based on the history of a typical trauma and on the pain experienced by the subjects at certain parts of the ligament on direct palpation and on stretching the ligament. The stability of the joint, tested by attempted abduction, was unimpaired. During these tests reflex muscular responses could be recorded by EMG in sartorius and semimembranosus, and occasionally in vastus medialis. During the attempted abduction at the *injured* knee joint pain receptors were activated, as was evident from the pain the subjects always experienced. However, both the muscular responses and the pain could be abolished by injecting a small amount of an anaesthetic at the site of 'partial rupture' of the ligament. It seems likely that the muscular responses obtained on stretching the *injured* ligament originated in pain receptors normally not activated when an intact ligament is stretched within reasonable limits. Further studies are being made with a view to throwing more light on this problem.

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